THE

American Journal of Physiology

VOL. XXXII AUGUST 1, 1913 NO. IV

STUDIES IN FATIGUE

I. Fatigue as Affected by Changes of Arterial Pressure

By CHARLES M. GRUBER

[From the Laboratory of Physiology in the Harvard Medical School.]

THAT increased muscular effort causes an increased arterial pressure has long been known. The reverse of this relation —the effect of arterial pressure on muscular efficiency — seems not to have attracted much attention. After carefully searching through the literature I have been unable to find any references to observations on the effects of changes of arterial pressure, either increase or decrease, on neuro-muscular fatigue. In a recent paper [1] Cannon and Nice have called attention to the need of more exact study of the relation between the circulation and muscular ability, and the work here reported was undertaken with the purpose of making clearer these relations.

The Method

Cats, anaesthetized with urethane (2 gm. per kilo, by stomach) were used in the experiments. By making a small slit through the skin on the outer side of the left thigh, the sciatic nerve was isolated, cut, and its distal end fastened in a Sherrington shielded electrode. The electrode was then held in place by fastening around it, with paper clips, the two flaps of skin.

[1] Cannon and Nice: this Journal, 1913, xxxii, p. 80.

Through another small slit in the skin the tendon of the left *tibialis anticus* muscle was isolated from its insertion. The tendon was then fastened to a muscle lever by a string passing about a series of pulleys. These pulleys were arranged so that the muscle pulled in its normal direction. One leather loop about the hock and another around the foot just below the fastening of the tendon bound the leg to the board and made a very satisfactory nerve muscle preparation. This preparation had its normal blood supply, unaltered except by the cutting of the sciatic nerve.

The stimulating current in every case was a break induction shock, obtained from a Martin vulcanite knife-blade key [2] operated by an electro-magnet as follows. A soft iron bar was pivoted near its centre to an upright board. Below one end of the bar was an electro-magnet, working in opposition to a flat steel spring attached to the other end of the bar. An upright iron rod, fastened near the centre of the bar, was connected at the other end (by a wire link) to the inverted brass triangle of the Martin key. Thus as the upright rod was moved to and fro it moved the knife blade making and breaking the circuit through the mercury in the key. A motor running at a uniform rate was used to revolve a metallic cylinder provided with projecting points, which made and broke the current in the electro-magnet circuit, usually 160 times per minute. In a few experiments lower rates were used. This rate was slow enough to produce not vasoconstriction but vasodilation [3] in the vessels of the stimulated muscle. The secondary of the inductorium was connected with the shielded electrode on the sciatic nerve.

The muscle lever consisted of a piece of light straw 20 cm. in length from the axis to the writing point. The tendon was attached 4.5 cm. from the axis and at the moment of contraction began to pull against the tension developed in a spring which was attached at the same position on the lever. This spring, in the majority of cases, had a tension of 120 gm. the moment the muscle began to contract, but in a few cases it had an initial tension of as much as 250 gm. For each 2.5 cm. excursion of the muscle lever on the drum the spring increased 15 gm. above the original 120.

[2] MARTIN: this Journal, 1910, xxvi, p. 181.

[3] BOWDITCH and WARREN: Journal of physiology, 1886, vii, p. 416; BRADFORD: *Ibid.*, 1889, x, p. 390.

The blood pressure was registered from the right carotid or femoral artery by means of a mercury manometer. A time marker which indicated intervals of thirty seconds was placed at the atmospheric pressure line of the manometer. Thus, at any given muscular contraction, the height of blood pressure was simultaneously recorded.

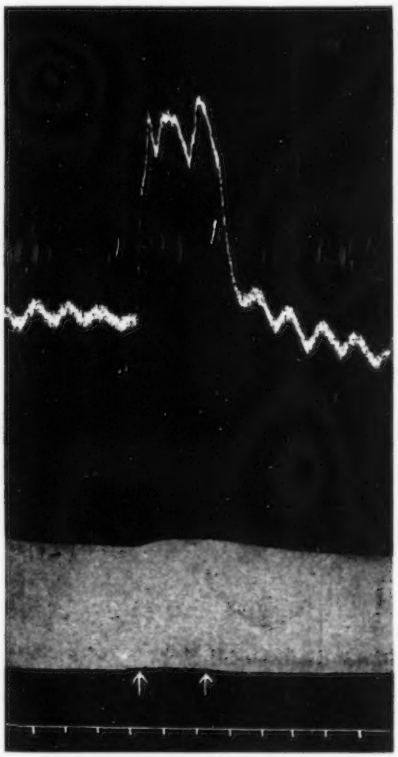


FIGURE 1. In this and all following records, the upper curve indicates the blood pressure the middle line muscular contraction, and the lower line the time in 30 seconds (also zero blood pressure). Between the arrows the exposed cervical spinal cord was stimulated.

The blood-pressure style, muscle lever and time marker were all placed in a vertical line on the kymograph surface. The rate of the drum was always slow and the muscle contractions were recorded close together.

Several methods were used to vary the blood pressure. Those employed to raise it were: (1) stimulation of the spinal cord in the cervical region with platinum electrodes, and (2) stimulation of the left splanchnic nerves with the adrenal glands tied off. The electrode used on the splanchnic nerves was similar to that used by Cannon and Nice.[4] The methods employed to lower the pressure were: (1) simple compression of the thorax; (2) pulling on a loop placed around the aorta just above its iliac branches, and (3) injection of very small doses of adrenalin [5] through a cannula in the left external jugular vein.

[4] *See* CANNON and NICE: *Loc. cit.*, p. 71.

[5] *See* CANNON and LYMAN: this Journal, 1913, xxxi, p. 376.

The Effects of Increased Arterial Pressure

In taking up the results of variations of arterial pressure on fatigue, it is convenient to consider first, the effect of rise of pressure. This rise was brought about in the experiment represented in Fig. 1, by stimulation of the cervical spinal cord, and in Figs. 2 and 3 by stimu-

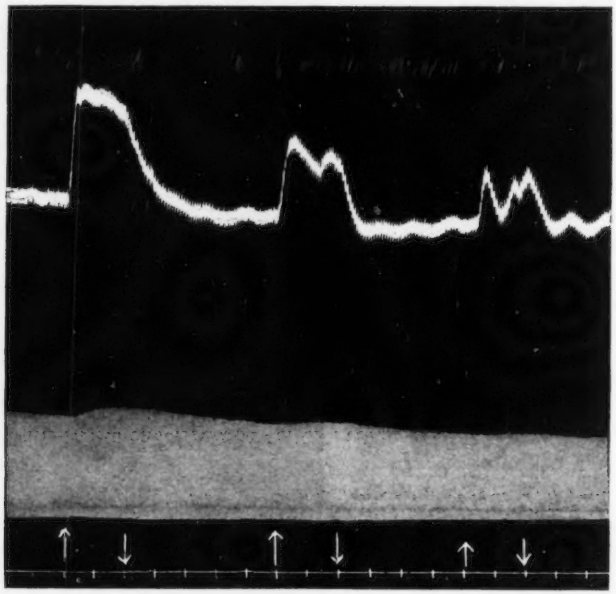
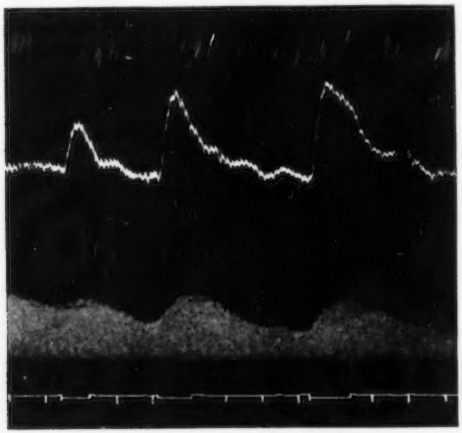


Figure 2. Stimulation of the left splanchnic nerves (left adrenal gland tied off) during the period indicated by the arrows.

lation of the left splanchnic nerves after the left adrenal gland was tied off. The original blood pressure in Fig. 1 was 120 mm. of mercury. This was increased 62 mm. with an increase of only 8.4 per cent in the height of muscle contraction. In Fig. 2 the original pressure was 100 mm. of mercury. By increasing this pressure 32 mm. there resulted a synchronous betterment of 9.8 per cent in the height of muscular contraction. In Fig. 2B the arterial pressure was raised 26 mm. and the height of contraction increased correspondingly 7 per cent. In Fig. 2C no appreciable betterment can be seen although the blood

pressure rose 18 mm. In Fig. 3 the original blood pressure was very low — 68 mm. of mercury. This was increased in Fig. 3A 18 mm. with an increase in the height of contraction of 20 per cent; in Fig. 3B 24 mm. with a corresponding increase of 90 per cent and in Fig. 3C 30 mm. with a betterment of 125 per cent.

That this increase in the height of contraction is due to the increase in blood pressure seems almost beyond dispute. It is evident from



A B C

FIGURE 3. During the period indicated in the time line the left splanchnic nerves were stimulated. The vessels of the left adrenal gland were tied off.

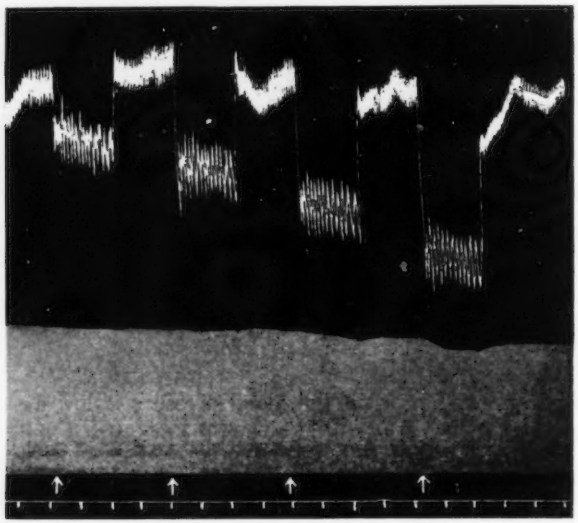
these observations that when the blood pressure is low a small rise has many times the effect that it has when the pressure is high. There is abundant evidence that fatigue products accumulate in a muscle doing work.[6] As the pressure rises, thus bettering the circulation through the active muscle, these products are carried away more rapidly. Moreover, since the stimulation of the sciatic nerve used

[6] DUBOIS, REYMOND: Archiv für Anatomie, 1859, p. 849; RANKE: Archiv für Anatomie, 1863, pp. 422–450; MOLESCHOTT and BATTISTINI: Archives italiennes de biologie, 1887, viii, pp. 90–124; GLEISS: Archiv für die gesammte Physiologie, 1887, xl, pp. 69–75; LANDSBERGER: Archiv für die gesammte Physiologie, 1891, l, pp. 339–363; FLETCHER and HOPKINS: Journal of physiology, 1906–07, xxxv, p. 247; LEE: this Journal, 1907, xviii, p. 267.

in these experiments was too slow to cause vasoconstriction, but instead caused vasodilation the opportunity for the blood to pass readily in large volume through the vessels and thus to carry away a large per cent of the accumulated waste products of fatigue, is obvious. Ranke [7] found that if a muscle is deprived of its circulation and fatigued to a standstill, and then the circulation restored, it again contracts for a short time due to the neutralization of the waste-products by the blood.

The Effect of Mechanical Decrease of Arterial Pressure

If an increase in blood pressure produces an increase in the height of muscle contraction it is natural to suppose that a decrease in



A B C D

FIGURE 4. The arrows indicate the point at which the thorax began to be compressed.

blood pressure would have the opposite effect. Such is the case only when the blood pressure falls below the region of 90 to 100 mm. of mercury. Thus, if the arterial pressure is 150 mm. of mercury it

[7] RANKE: Archiv für Anatomie, 1863, p. 446.

has to fall approximately 55 to 65 mm. before it produces a decreased effect in the height of contraction. Fig. 4 is a record in which the blood pressure was decreased by compressing the thorax. The record shows that, when the pressure dropped from 120 to 100 mm. of mercury there was no appreciable decrease in the height of contraction; when to 90 mm. of mercury there resulted a decrease of 2.4 per cent; when to 80 mm. of mercury a 7 per cent decrease and when to 70 mm. a 17.3 per cent decrease.

Thus about 90 to 100 mm. of mercury may be called the critical region at which the decrease in blood pressure is accompanied by a concurrent decrease in the height of muscular contraction. It is near that point that the blood flow is in danger of being insufficient.

Results similar to those represented in Fig. 4 were obtained by pulling on a string looped about the aorta just above the iliac branches.

FIGURE 5. During the period indicated in the time line 0.3 c.c. of a 1:100,000 solution of adrenalin was injected into the left external jugular vein.

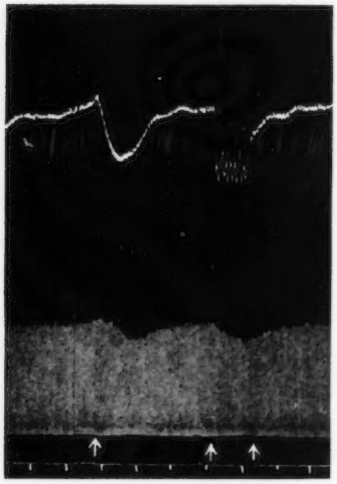
THE EFFECT OF DECREASING THE ARTERIAL PRESSURE BY ADRENALIN

In the third series of experiments adrenalin was used to lower the blood pressure. Cannon and Lyman found that adrenalin injected in small doses — 0.1 to 0.2 c.c. of 1: 100,000 solution — produces a fall in blood pressure until a critical region was reached. Below this region the same amount injected produces a rise.[8]

In Fig. 5, 0.3 c.c. of 1: 100,000 solution of adrenalin was injected slowly into the right external jugular vein. The blood pressure dropped from 120 mm. to 96 mm. of mercury. With this decrease in arterial pressure there was a resultant betterment of 14.3 per cent

[8] *Loc. cit.*, p. 389.

in the height of muscular contraction. Since this fall of pressure is within the critical zone a uniform contraction or a decrease would be expected. A similar drop in arterial pressure is shown in Fig. 4B. This was brought about mechanically and there resulted a decrease of 2.4 per cent in the height of contraction. When at 100 mm. no change resulted. This betterment may be accounted for by the effect of adrenalin.[9]



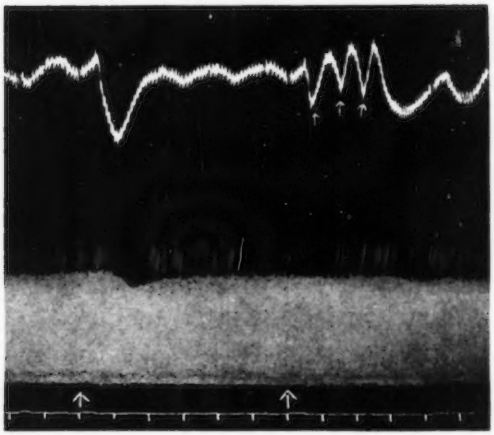
A B

FIGURE 6. In A, at the point indicated by an arrow, 0.3 c.c. of a 1:100,000 solution of adrenalin was injected intravenously. In B, the arrows indicate the period during which the thorax was compressed.

A quite different effect is shown in Fig. 6A. The same amount of adrenalin — 0.3 c.c. 1: 100,000 solution — was injected as in the case represented in Fig. 5. In this case, however, the blood pressure fell from a low region to a region below the critical region — 108 to 90 mm. of mercury. Instead of a betterment in the height of contraction, as in the preceding experiment, there was a decrease of 18.7 per cent. The same result followed when the pressure was lowered by compressing the thorax. In Fig. 6B an almost equal fall of blood pressure was thus produced and a fall of 17.7 per cent in the height of contraction resulted.

Fig. 7 confirms Fig. 6 very well. In Fig. 7A, as in Fig. 6A, 0.3 c.c. of 1: 100,000 solution of adrenalin was injected. There was a fall in blood pressure from 102 to 80 mm. of mercury and a corresponding fall of 17.7 per cent in the height of contraction. In Fig. 7B the same quantity of adrenalin was injected but here the blood pressure was maintained above the critical point by stimulating the left splanchnic nerves (with the left adrenalin vessels tied) at the points indicated by arrows. No fall in the height of muscular contraction resulted. This seems to indicate that, in these cases, the muscular contraction is

[9] *See* CANNON and NICE: *Loc. cit.*, p. 74.



A B

FIGURE 7. In A, the arrow indicates the point at which 0.3 c.c. of a 1:100,000 solution of adrenalin was injected. In B, the lower arrow indicates the point at which the same quantity of adrenalin was injected. The upper three arrows indicate the points at which the left splanchnic nerves were stimulated. The left adrenal gland was tied off.

dependent upon the blood flow rather than upon the action of adrenalin.

SUMMARY

1. Increasing the arterial pressure, thus bettering the circulation, increases the height of muscular contraction 100 to 125 per cent when the blood pressure is below 90 to 100 mm. of mercury but only 5 to 25 per cent when the pressure is above this region.

2. As the blood pressure or the circulation is decreased, the height of muscular contraction is lowered, but this takes place only when the arterial pressure falls below 90 to 100 mm. of mercury.

3. Small doses of adrenalin — 0.1 to 0.3 c.c. of a 1: 100,000 solution — slowly injected intravenously, cause a fall of arterial pressure. When this fall is not below the critical region — about 90 to 100 mm. of mercury — a betterment in the height of contraction results; when below this zone the result is the opposite.

I wish to express my thanks to Dr. W. B. Cannon for valuable suggestions offered me during these experiments.

CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF
THE MUSEUM OF COMPARATIVE ZOÖLOGY AT
HARVARD COLLEGE, No. 238

ON CERTAIN DISTINCTIONS BETWEEN TASTE AND SMELL

BY GEORGE HOWARD PARKER AND ELEANOR MERRITT STABLER

INTRODUCTION

PERHAPS the most widely accepted distinction between taste and smell is that taste is excited by materials in the state of solution and smell is called forth by substances in a vaporous or gaseous condition. This distinction is based upon an experiment on sensory stimulation published by E. H. Weber in 1847 in which he showed that a dilute solution of eau de cologne, though highly odorous when sniffed, produced no sensation of smell when poured into the nose. Nagel, many years later (1894), was so fully persuaded of the correctness of this view that he went so far as to deny a sense of smell to water-inhabiting vertebrates, such as the fishes, etc., maintaining that solutions were inodorous and that the so-called olfactory organs of fishes and other water-inhabiting animals were more in the nature of organs of taste than organs of smell.

Meanwhile, Aronsohn (1884), who had repeated Weber's experiment, declared that substances in solution when poured into the nose, could be smelled, provided they were dissolved in a physiological salt solution that was kept warmed to about the temperature of the human body. This conclusion was confirmed by Vaschide (1901), and by Veress (1903), though the latter showed that the solutions tested were rather in the nature of heterologous than homologous stimuli. Thus, notwithstanding the opinion of Zwaardemaker (1895), Haycraft (1900), and others, it seems to us that solutions must be admitted to

be stimuli for the olfactory surfaces, a conclusion in agreement with the belief expressed many years ago by Müller (1837, p. 484) and reiterated recently by von Frey (1904, p. 334) and even by Nagel (1904, p. 600), that in normal olfaction in man the odorous particles are caught on the moist olfactory surfaces and dissolved there before they can act on the nerve terminals. The belief that solutions are stimuli for the olfactory surface is also favorable to the view that fishes and water-inhabiting amphibians may have as true an olfactory organ as air-inhabiting vertebrates do, a conclusion suggested by the observations of Aronsohn (1884, p. 164) on goldfish, and of Baglioni (1909a, p. 719) on Balistes, and proven by the experiments of Parker (1910, 1911) on Ameiurus and Fundulus, of Sheldon (1911) on Mustelus, and of Copeland (1912) on Spheroides. It must, therefore, be admitted that in both air-inhabiting and water-inhabiting vertebrates the stimulus for the olfactory organs is in reality a solution and, since this is also true for the sense of taste, the problem naturally presents itself of the real difference between smell and taste.

In attacking this question it seemed well to select as a stimulus a substance that was relatively simple chemically, that was easily obtainable in pure form, and that was at once a stimulus for both smell and taste. Such a substance was found in ethyl alcohol. This well-known reagent has a characteristic odor and a well-marked sweetish taste. Our preliminary tests were carried out with a high-grade laboratory product, but our final tests were made with Kahlbaum's alcohol of the highest obtainable purity and guaranteed to contain not over 0.2 per cent water. The alcohol was received in sealed tin containers and was kept by us in glass-stoppered bottles. In carrying out our tests we endeavored to determine the lowest dilutions at which the sweet taste and the characteristic smell could be excited as well as that which would call forth the first signs of sting from those surfaces of the mouth that are unprovided with gustatory organs. In order that the various concentrations of alcohol used as stimuli for the several sense organs might be compared, we have made all dilutions on the basis of the relative number of molecules and expressed them in terms of molecular solutions or corresponding gas dilutions and not in per cents as has been done heretofore by many investigators.

Taste from Ethyl Alcohol

So far as the taste of ethyl alcohol was concerned, it was our object to ascertain the weakest dilution at which the sweet taste could be distinguished. We therefore prepared a 10 mol. solution of the purest alcohol and this we used as a stock from which weaker solutions were made as they were needed. In each test the subject was required to close the eyes, close the nose by pinching it between thumb and finger, and receive on the extended tongue near the tip two drops of the fluid to be tested. The glass dropping apparatus that we used delivered 297 drops of dilute alcohol per 5 c.c. The two drops generally employed in these experiments represent, therefore, about 0.017 c.c. The fluids used in these tests were dilute alcohol and, as a check, distilled water. After the fluid had been on the tongue a short time and before the nose was released, the subject was required to state whether the fluid was distilled water or dilute alcohol. Preliminary tests showed that a fold of filter paper wet with dilute alcohol and held in the cavity of the mouth, but not in contact with its walls, could not be distinguished from a similar fold wet with distilled water. Hence there was no reason to suppose that the determinations were influenced by any diffusion of alcoholic vapor from behind into the nasal chambers. It is believed that the determinations depended absolutely on the action of the materials on the surface of the tongue. The subjects of the tests were the authors of the paper, one experimenting on the other. After each test the subject washed out the mouth with tepid tap water and rested for a period of about five minutes before another test was made.

To a solution of alcohol of 5 mol. strength both subjects responded with perfect accuracy and, on repeated trials, they always distinguished the dilute alcohol from the distilled water. At a dilution of 3 mol. the sweet taste of the alcohol was very faint. In ten tests nine were correct and one a failure. On applying the two drops of dilute alcohol to the tongue, both subjects regularly experienced a slight indescribable sensation before the characteristic sweet taste of the alcohol appeared. This preliminary sensation was quickly and completely obliterated by the sweet taste that followed. At a dilution of 2 mol. the subjects failed five times in ten trials and we there-

fore conclude that the weakest solution that can call forth the sweet sensation with certainty is of about 3 mol. strength.

A comparison of the sweet taste of cane sugar with that of ethyl alcohol showed the former to be much the more effective stimulus. While it was possible to distinguish with certainty a solution of ethyl alcohol of not less than 3 mol. concentration, a solution of cane sugar of only $2\frac{1}{6}$ mol. concentration was easily recognized and, judging from the results of Lemberger (1908, p. 303), still more dilute solutions can be easily distinguished. Ethyl alcohol is to be regarded, therefore, as a not very efficient stimulus for the sweet taste.

Irritation from Ethyl Alcohol

Distilled water and solutions of alcohol were applied to certain non-gustatory surfaces of the mouth in the same manner as to the tongue, with the intention of determining the weakest dilution that would call forth the slight stinging and warming effect of alcohol on such sufaces. Three regions were selected for these tests: first, the region on the floor of the mouth between the lower incisors and the root of the tongue; secondly, the space between the lower lip and the lower incisors; and thirdly, the inner face of the cheek.

In the region between the lower incisors and the root of the tongue, the results were most uniform. At a concentration of 10 mol. ten correct determinations were made in ten trials. At 5 mol., however, there were six failures in ten trials.

In the region between the lower lip and the incisors the results were less uniform than on the floor of the mouth proper. One subject (E. M. S.) distinguished with certainty the 5 mol. solution of alcohol but failed generally on the 3 mol. solution; and the other subject (G. H. P.) distinguished the 10 mol. solution but failed on the 5 mol. solution.

The records of the tests on the inner surfaces of the cheeks show a somewhat similar difference. A 10 mol. solution of alcohol was always distinguished with certainty from distilled water by one subject (E. M. S.) and poorly distinguished by the other (G. H. P.). At a dilution of 5 mol. both subjects failed to distinguish between the water and the distilled alcohol. In this, as in the preceding trials, one subject (E. M. S.) proved to be somewhat more sensitive than the

other (G. H. P.), a condition probably dependent upon the greater youthfulness of the former.

The sensations produced in these tests were described in a variety of ways, such as faintly warming, warmish sting, slightly stinging, prickling, etc., but they all partook in general of the nature of slight irritations. They probably result from the stimulation of sense organs which have recently been designated as those of the common chemical sense (Parker, 1912), and which probably pervade many of the peripheral mucous surfaces of the body.

The Smell from Ethyl Alcohol

In determining the weakest dilution at which the characteristic smell of alcohol could be detected, a method of procedure different from that used for taste had to be employed. This was in essentials the method that had been used by Valentin (1850), Fischer und Penzoldt (1886), and others. Our own procedure was as follows: Two glass battery jars of equal capacity, 1340 c.c., were cleaned till they gave the least possible odor. It was found impossible to free such jars entirely from smell. A careful examination always disclosed a faint clay-like odor, which, from its constancy, we were led to believe was due to the glass itself. When the two jars were indistinguishable in this respect, a drop of distilled water was put in one and a drop of dilute alcohol in the other. Both jars were covered and the fluids allowed to evaporate completely, a process which was facilitated by the introduction of a small electric fan, through the cover of the jar. After the complete evaporation of the fluids, the jars were tested in sequence by the subject, who, with eyes closed, was allowed a full breath through the nose from first one and then the other jar. The subject was then required to state in which jar the alcohol had been evaporated. The jars were then carefully washed and, after having been dried, were tested for their own smell and prepared for another trial.

The results obtained from these tests were remarkably uniform and constant for the two subjects. Both subjects distinguished with invariable correctness the jar in which a drop of a 10 mol. solution of alcohol had been evaporated from the one in which an equal amount of distilled water had been vaporized. When a drop of dilute alcohol

of 5 mol. concentration was evaporated in the jar, six failures in ten were made. Taking into account the dilution due to the evaporation into the known volume of air in the jar, the results may be stated as follows: both subjects detected the alcohol in an aerial dilution of $\frac{1}{7960}$ mol., but failed to detect it at $\frac{1}{15,920}$ mol. In other words the most considerable dilution at which the alcohol could be detected by the olfactory apparatus was about $\frac{1}{8000}$ mol.

This determination was obtained by the use of Kahlbaum's purest grade of alcohol. The preliminary trials made with the high-grade laboratory alcohol gave a very different result. The jar in which the laboratory alcohol had been evaporated could be distinguished when the contents were at a dilution of $\frac{1}{200,000}$ or even $\frac{1}{400,000}$ mol. The odor noted at these dilutions, however, had a sharp and penetrating quality quite unlike that of alcohol and was without question due to some impurity. In the test with the Kahlbaum alcohol, the odor remained constantly alcoholic to the weakest dilution that could be smelled. We therefore believe that the limit of dilution, $\frac{1}{8000}$ mol., found by us for the odor of ethyl alcohol is a reliable determination uninfluenced by impurities.

The only previous record of such a determination that we have been able to find is that given by Passy (1892[b], p. 1140), who states that 0.250 mg. of ethyl alcohol in a litre of air is the least concentration at which alcohol can be detected by its odor.[1] This is equivalent to a dilution of $\frac{1}{184,000}$ mol., which is so near that of the least perceptible dilution of our laboratory stock that we suspect that this determination, like that for our laboratory stock, was influenced by an impurity and does not represent the real limit for pure alcohol.

Discussion

It appears to us that the evidence is sufficient to justify the conclusion that in vertebrates the stimulus for smell is a substance dissolved in the fluids that bathe the olfactory surface and that in this respect smell and taste are similar. The difficulty in imitating a normal stimulation of the olfactory organs by solutions experimentally

[1] Passy (1892,[a] p. 307) elsewhere states that $\frac{1}{200}$ gm. of ethyl alcohol in a litre of air is only slightly perceptible. This concentration is twenty times that referred to by Passy as the lowest concentration that can be smelled.

introduced into the nose of air-inhabiting animals is due in our opinion to the inability of the investigator to reproduce the olfactory solvent. This material, the slimy covering of the olfactory surface, is very different from water or even warmed physiological salt solution. Hence, it is not surprising that odorous substances dissolved in these media should not act as normal stimuli for the olfactory surfaces of air-inhabiting vertebrates. Were it possible to imitate closely the olfactory solvent, we believe that there would be no difficulty in stimulating the olfactory organs with solutions made up in this solvent. The fact, known even to Weber (1847, p. 351), that water introduced into the human nose will cause a temporary loss of the power of smell, is enough to show the extreme sensitiveness of the olfactory organ and to suggest that any fluid, except that which is normal to it, may be physiologically disturbing to its surface. Hence, we put at naught those experiments that have thus far yielded negative results on introducing odorous solutions into the nose and believe that these results are dependent upon the disturbing effect of the solvent rather than on the inability of the olfactory organs to be stimulated by dissolved materials. In fishes the olfactory surfaces are apparently undisturbed by the water that bathes them, but in air-inhabiting vertebrates these surfaces seem to have become adapted to a well-developed slimy covering and thus to have lost their ability to respond normally to simple aqueous solutions. It is this loss of responsiveness that has led, in our opinion, to the degeneration of the olfactory apparatus in such mammals as the whales, whose aquatic habits, in comparison with those of fishes, have been secondarily acquired. We therefore definitely abandon the idea that taste and smell differ on the basis of the physical condition of the stimulus, a state of solution for taste, a gaseous or vaporous condition for smell, and maintain that both senses are stimulated by solutions, though in smell, at least for air-inhabiting vertebrates, the solvent is of a very special kind.

If the senses of taste and smell are stimulated by solutions, the probability that they are both chemical senses, as maintained long ago by Nagel (1894), is thereby greatly increased, and from this standpoint a partial distinction between them may be drawn on the basis of the solutes. Most substances that we smell have no taste, and most substances that we taste are without smell. Thus the olfactory sense is attuned to one set of substances and the gustatory

to another. But this distinction has numerous exceptions, for not a few organic substances, like alcohol for example, have both taste and smell, and, judging from the work of Veress (1903), there are inorganic salts with smells as well as tastes. Nevertheless the distinction pointed out seems to us to have some value.

But the difference between taste and smell that we believe to be of a still more general character is a quantitative one; we smell very dilute solutions, we taste only relatively strong ones. This difference appears most clearly when we deal with the dilution of the stimulus as expressed in terms of molecular solutions rather than in per cent, for this method allows us to compare mixtures of gaseous materials with solutions. If, from this standpoint, we compare the stimuli for some of the most penetrating odors with those of the strongest tastes, the contrast becomes very striking. One of the strongest tastes is the bitter taste of quinine hydrochloride and this can be excited by a solution as dilute as $\frac{1}{25,000}$ mol. One of the strongest smells known is that of mercaptan of which, according to Fischer und Penzoldt (1886, p. 8), 0.01 mg. evaporated in 230 c.c. of air gives a perceptible odor. Assuming the substance used to have been *methyl* mercaptan and stating the matter in terms of a molecular solution, this substance can be smelled at a dilution of $\frac{1}{1,104,000,000,000}$ mol. Thus it appears that when we compare the most powerful tastes with the most powerful smells, we find that the olfactory organ of man is responsive to a dilution over 44,000,000 times greater than that to which the sense of taste responds. But this comparison is obviously inexact since the stimuli for the two senses are different substances. Hence, the importance of making this comparison with a substance that is a stimulus for both smell and taste. Ethyl alcohol, as recorded in this paper, can barely be recognized by taste at a concentration of 3 mol., but it is discernible by smell at a dilution of about $\frac{1}{80,000}$ mol. This comparison, then, like that between mercaptan and quinine, shows that the olfactory organs of man are much more sensitive to ethyl alcohol than are his gustatory organs, the ratio of the stimuli being about 1 to 24,000.

Although we believe that the distinction between taste and smell as presented in the preceding paragraph is a valid one, we are perfectly aware that the measurements upon which this opinion is based are not measurements of the real stimuli. They show the relative

concentration of molecules in the materials supplied to the tongue and to the moist olfactory surfaces; they do not show the molecular concentrations in contact with the actual end-organs. It is probable, however, that in both smell and taste the concentration of stimulating material at the end-organ is not far from that in the adjacent source, the air in the olfactory organ or the solution on the surface of the tongue. We therefore believe that we are correct in concluding that we smell enormously attenuated solutions and taste only relatively strong ones. In this respect the two senses may be said to differ from each other more or less as ordinary scales do from a chemical balance; taste is used in determining the presence of relatively large amounts of substance, smell for only the most minute quantities. Hence, taste is inoperative except when the source is very near at hand, usually in the mouth, whereas smell may be active when the source is far distant, the dilution suffered by the stimulating substance in its spread not having been sufficient to have brought it below the concentration necessary for stimulation.

Summary

1. The weakest aqueous solution of ethyl alcohol that could be tasted was of about 3 mol. concentration.

2. The weakest aqueous solutions of ethyl alcohol that just stimulated the non-gustatory surfaces of the mouth were as follows: for the region between the lower incisors and the root of the tongue, 10 mol.; for the region between the lower lip and the incisors, from 5 to 10 mol.; and for the inner surface of the cheek, 10 mol.

3. The weakest aerial dilution of ethyl alcohol that could be smelled was about $\frac{1}{8000}$ mol.

4. Ordinary grades of ethyl alcohol may excite smell at dilutions as low as $\frac{1}{4000}$, $\frac{1}{6000}$ mol., but this is probably due to impurities.

5. Both smell and taste are stimulated by solutions. In air-inhabiting vertebrates the olfactory solvent is a slimy fluid of organic origin and not easily imitated. Hence the olfactory organs of these animals are not appropriately stimulated by ordinary aqueous solutions.

6. Beside the different chemical nature of the stimuli, that for the sense of taste is a relatively strong solution, that for smell a rela-

tively weak solution. The dilutions of ethyl alcohol as minimum stimuli for smell and taste are as 1 to 24,000.

Bibliography

Aronsohn, E.: 1884. Beiträge zur Physiologie des Geruchs. Arch. für Anat. u. Physiol., physiol. Abt., Jahrg., 1884, pp. 163–167.

Baglioni, S.: 1909a. Zur Physiologie des Geruchsinnes und des Tastsinnes der Seetiere. Zentralbl. für Physiol., Bd. 22, pp. 719–723.

Baglioni, S.: 1909b. Contributions expérimentales à la physiologie du sens olfactif et du sens tactile des animaux marins ("Octopus" et quelques poisson). Arch. Ital. Biol., tome 52, pp. 225–230.

Copeland, M.: 1912. The Olfactory Reactions of the Puffer or Swellfish, Spheroides maculatus (Bloch and Schneider). Journ. Exper. Zoöl., xii, pp. 363–368.

Fischer, E. und F. Penzoldt: 1886. Ueber die Empfindlichkeit des Geruchsinnes. Sitzungsber. phys.-med. Soc., Erlangen, Heft 18, pp. 7–10.

Frey, M. von: 1904. Vorlesungen über Physiologie. Berlin, 8vo, x + 392 pages.

Haycraft, J. B.: 1900. The Sense of Smell. In E. A. Schäfer, Textbook of Physiology, ii, pp. 1247–1258.

Larguier des Bancels, L.: 1912. Le Gout et l'Odorat. Paris, 8vo, x + 94 pages.

Lemberger, F.: 1908. Psychophysische Untersuchungen über den Geschmack von Zucker und Saccharin (Saccharose und Krystallose). Arch. für ges. Physiol., Bd. 123, pp. 293–311.

Müller, J.: 1837. Handbuch der Physiologie der Menschen. Band 2. Coblenz, 8vo, 780 pages.

Nagel, W.: 1894. Vergleichend-physiologische und anatomische Untersuchungen über den Geruchs-und Geschmackssinn und ihre Organe. Bibl. Zool., Heft 18, viii + 207 pages, 7 Taf.

Nagel, W.: 1904. Handbuch der Physiologie des Menschen. Band 3. Erste Hälfte. Braunschweig, 8vo, xvii + 806 pages.

Parker, G. H.: 1910. Olfactory Reactions in Fishes. Journ. Exper. Zoöl., viii, pp. 537–542.

Parker, G. H.: 1911. The Olfactory Reactions of the Common Killifish, Fundulus heteroclitus (Linn.). Journ. Exper. Zoöl., x, pp. 1–5.

Parker, G. H.: 1912. The Relation of Smell, Taste, and the Common Chemical Sense in Vertebrates. Journ. Acad. Nat. Sci., Philadelphia, xv, pp. 219–234.

PARKER, G. H., AND R. E. SHELDON: 1913. The Sense of Smell in Fishes. Bull. United States Bureau Fisheries, xxxii, pp. 33–46.

PARKER, G. H., and E. M. STABLER: 1913. Taste, Smell and Allied Senses. Science, N. S., xxxvii, p. 269.

PASSY, J.: 1892a. Sur les minimums perceptibles de quelques odeurs. Compt. Rend. Acad. Sci., Paris, tome 114, pp. 306–308.

PASSY, J.: 1892b. Les propriétés odorantes des alcools de la série grasse. Compt. Rend. Acad. Sci., Paris, tome 114, pp. 1140–1143.

SHELDON, R. E.: 1911. The Sense of Smell in Selachians. Journ. Exper. Zoöl., x, pp. 51–62.

VALENTIN, G.: 1850. Grundriss der Physiologie der Menschen. Dritte Auflage. Braunschweig, 8vo., vii + 733 pages, 5 Taf.

VASCHIDE, N.: 1901. L'expérience de Weber et l'olfaction en milieu liquide. Compt. Rend. Soc. Biol., Paris, ann. 53, pp. 165–167.

VERESS, E.: 1903. Ueber die Reizung des Riechorgans durch directe Einwirkung riechende Flussigkeiten. Arch. ges. Physiol., Bd. 95, pp. 368–408.

WEBER, E. H.: 1847. Ueber den Einfluss der Erwärmung und Erkältung der Nerven auf ihr Leitungsvermögen. Arch. Anat. Physiol. und wissenschaftl. Med., Jahrg., 1847, pp. 342–356.

ZWAARDEMAKER, H.: 1895. Die Physiologie des Geruchs. Leipzig, 8vo, vi + 324 pages.